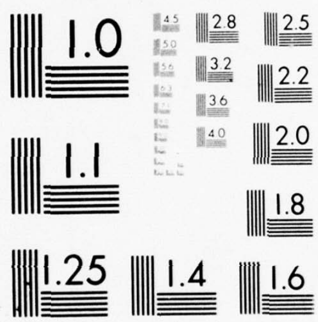
AD-A046 509 TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MASS F/G 17/7
AIR TRAFFIC CONTROL EXPERIMENTATION AND EVALUATION WITH THE NAS--ETC(U)
AUG 77 S PROTOPAPA DOT-TSC-707-1
UNCLASSIFIED TSC-FAA-76-22-1 FAA-RD-75-173-1 NL

| OF |

AD
A046509

END
DATE
FILMED
12-77
DDC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

(6)

REPORT NO. FAA-RD-75-173,I

ADA046509

AIR TRAFFIC CONTROL EXPERIMENTATION AND EVALUATION WITH THE NASA ATS-6 SATELLITE

Volume I: Executive Summary

Sejfi Protopapa

U.S. DEPARTMENT OF TRANSPORTATION
Transportation Systems Center
Kendall Square
Cambridge MA 02142

AUGUST 1977

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINSTRATION
Systems Research and Development Service
Washington DC 20591

(12) 43p.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
(18) FAA-RD-75-173-1 (19)		(11)
4. Title and Subtitle: (6) AIR TRAFFIC CONTROL EXPERIMENTATION AND EVALUATION WITH THE NASA ATS-6 SATELLITE. Volume I. Executive Summary*		5. Report Date: August 1977
		6. Performing Organization Code: (14) ~~DOT~~ TSC-FAA-76-22-1
7. Author(s): (10) Sejfi Protopapa		8. Performing Organization Report No.: D6-44052
9. Performing Organization Name and Address: U.S. Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge MA 02142		10. Work Unit No. (TRAIS): FA711/R7106
		11. Contract or Grant No.: (15) DOT-TSC-707-1
12. Sponsoring Agency Name and Address: *U.S. Department of Transportation* Federal Aviation Administration, Systems Research and Development Service, Washington DC 20591		13. Type of Report and Period Covered: (9) Final Report, Sep. 1973 - Dec. 1975
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The U.S. Department of Transportation (DOT), Federal Aviation Administration (FAA) program for air traffic control (ATC) experimentation and evaluation with the ATS-6 satellite was part of the Integrated ATS-6 L-Band Experiment. All tests were performed between September 1974 and April 1975. The U.S. DOT aeronautical program consisted of both ATC communications demonstration and technology tests. In support of the aeronautical satellite (AEROSAT) program, tests were designed to collect satellite-aircraft signal propagation data, evaluate L-band avionics hardware designs, and perform preliminary satellite voice and data communications demonstration tests.

The technology tests were composed of multipath channel characterization tests; modem tests of voice, data and ranging; and aircraft antenna tests. Multipath results include overland data. Comparisons of multipath sample results with model prediction are given. Voice modem intelligibility scores, digital data bit-error rates and ranging modem performance are presented parametrically as functions of C/N_o and S/I. Experimentally derived gain and multipath rejection performance data are given for the slot-dipole, phased-array and patch antennas for various aircraft/satellite geometries.

The demonstration tests of satellite supported communications for application to Oceanic ATC comprised two phases: demonstrations relating to U.S. concepts and practices, and demonstrations conducted as a joint effort between the U.S., the European Space Agency (ESA) and Canada.

The report consists of seven volumes: I-Executive Summary; II-Demonstration of Satellite-Supported Communications and Surveillance for Oceanic Air Traffic Control; III-Summary of U.S. Aeronautical Technology Test Program; IV-Data Reduction and Analysis Software; V-Multipath Channel Characterization Test; VI-Modem Evaluation Test; VII-Aircraft Antenna Evaluation Test.

17. Key Words	18. Distribution Statement
Satellite Communications, AEROSAT, Multipath, Delay-Doppler Scatter Function, Modem Evaluation, Voice Intelligibility, Bit-Error Rates, Ranging, Antennas, Phased Array, Slot Dipoles, L-Band, ATS-6 Sattelite	DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	42	

Form DOT F 1700.7 (8-72)

407 082 — i — LB

AIR TRAFFIC CONTROL EXPERIMENTATION AND EVALUATION WITH THE NASA ATS-6 SATELLITE

FINAL REPORT

This report consists of the following volumes.

Volume I
Executive Summary

Volume II
Demonstration of Satellite-Supported Communications and Surveillance for Oceanic Air Traffic Control

Volume III
Summary of U.S. Aeronautical Technology Test Program

Volume IV
Data Reduction and Analysis Software

Volume V
Multipath Channel Characterization Test

Volume VI
Modem Evaluation Test

Volume VII
Aircraft Antenna Evaluation Test

PREFACE

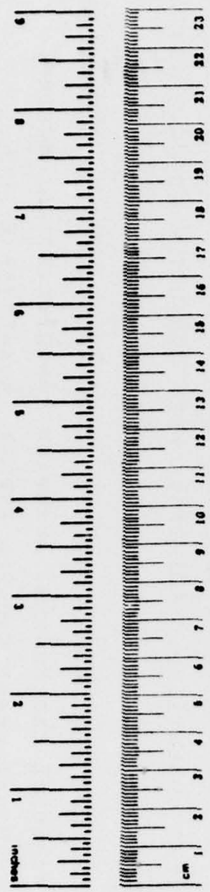
The U.S. Department of Transportation (DOT) aeronautical test program entitled "Air Traffic Control Experimentation and Evaluation with the NASA ATS-6 Satellite" was part of the Integrated ATS-6 L-Band Experiment. The overall ATS-6 L-band experiment was coordinated by the NASA/Goddard Space Flight Center (GSFC) and was international in scope. The following agencies were participants in the experiment: NASA/Goddard Space Flight Center; DOT/Federal Aviation Administration; DOT/Transportation Systems Center; DOT/U.S. Coast Guard; DOC/Maritime Administration; European Space Agency (ESA); and the Canadian Ministry of Transport and Department of Communications. Each participant performed tests in one or more of three categories; aeronautical, maritime safety, and maritime fleet operations. All tests were conducted in accordance with an overall integrated test plan coordinated by NASA/GSFC.

The U.S. DOT Aeronautical test program was under the direction and sponsorship of the Federal Aviation Administration, Systems Research and Development Service (SRDS), Satellite Branch, Mr. F. S. Carr, Chief. DOT/TSC conducted the technology tests, Mr. R.G. Bland, project engineer and FAA/NAFEC conducted the ATC demonstration tests, Mr. F.W. Jefferson, project engineer. Other key DOT/FAA personnel were Mr. V.E. Foose for the technology tests and Mr. R.J. Hilton for the ATC demonstration tests. The technology tests included multipath channel characterization, modem evaluation, and aircraft antenna evaluation. Results of these tests are presented in Volumes III through VII, and the results of the ATC demonstration tests are presented in Volume II.

METRIC CONVERSION FACTORS

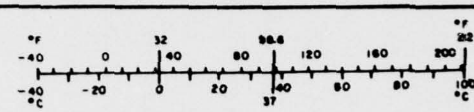
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SYMBOLS AND ABBREVIATIONS

AATMS	Advanced Air Traffic Management Systems
AERO/MAR	Aeronautical Marine
AEROSAT	Aeronautical Satellite Program
AGARD	Advisory Group for Aerospace Research and Development
ANBFM	Adaptive Narrowband Frequency Modulation (Modem)
ARTCC	Air Route Traffic Control Center
ASTRA	Applications of Space Techniques Relating to Aviation
ATC	Air Traffic Control
ATS-6	Applications Technology Satellite 6 (NASA)
BER	Bit-Error Rate
BPS	Bits Per Second
C/N_o	Ratio of Unmodulated Carrier Power to Noise Power Density, dB-Hz
CONUS	Continental United States
DOT	Department of Transportation
DPSK	Differential Phase-Shift Keying
ESA	European Space Agency
FAA	Federal Aviation Administration
GSFC	Goddard Space Flight Center
HF	High Frequency
Hz	Hertz
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IMCO	Inter-Governmental Maritime Consultative Organization
ITU/CCIR	International Telecommunication Union/ International Radio Consultive Committee
MARAD	Maritime Administration
NAFEC	National Aviation Facilities Experimental Center
NASA	National Aeronautics and Space Administration
NAT	North Atlantic
NBFM	Narrowband Frequency Modulation
OTP	Office of Telecommunications Policy

SYMBOLS AND ABBREVIATIONS (CONTINUED)

PB	Phonetically Balanced
PLACE	Position Location and Communication Equipment
RF	**Radio Frequency**
RMS	Root Mean Square
S/I	Ratio of Direct-Path Signal Power to Multipath Signal Power, dB
SRDS	Systems Research and Development Services (FAA)
TSC	Transportation Systems Center
URSI	International Union of Radio Science
USCG	U.S. Coast Guard
VHF	Very High Frequency

1. INTRODUCTION

The U.S. Department of Transportation, Federal Aviation Administration (FAA), pursuing national policy in concert with international organizations, during the 1974-1975 period conducted a series of technical and demonstration tests with the NASA Applied Technology Satellite, ATS-6, as a participant in the integrated L-Band experiment. The general objectives of this activity are contained in FAA program plans for the development of Air Traffic Control (ATC) systems utilizing satellite techniques of communication and surveillance. The objectives of these experiments fall into two major categories:

a. Technology data base and equipment development;

b. System demonstration of operational concepts.

The International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO), both member organizations of the United Nations, have encouraged participation in the ATS-6 L-Band Experiment. The FAA was joined by the European Space Agency (ESA) (formerly European Space Research Organization, ESRO) and the Canadian Ministry of Transport for the civil aviation experiments. In the maritime sector, the U.S. Coast Guard (USCG), the FAA and the European Space Agency conducted search and rescue demonstrations as well as L-Band voice and data satellite communications tests.

During the past decade, the FAA has conducted various satellite communications studies and tests in support of Oceanic and Continental (CONUS) Air Traffic Control (ATC) systems. Currently the FAA, ESA and Canada are developing coordinated test plans for the aeronautical satellite program, AEROSAT. This program is designed to test alternative ATC techniques and operational procedures for a future satellite based oceanic communications system.

The L-Band communication system provided by the NASA ATS-6 satellite constituted a unique opportunity to experimentally test, develop, and demonstrate satellite technology for the oceanic ATC system applications, as well as conduct channel propagation investigations for the CONUS ATC concepts of the future.

The FAA satellite communications and surveillance experiments were conducted under the leadership of the Systems Research and Development Service (SRDS) with the direct support of the Transportation Systems Center (TSC) for the technology tests, and the National Aviation Facilities Experimental Center (NAFEC) for the demonstration tests. In addition, several private companies and organizations provided support for the various test phases and activities of the FAA ATS-6 L-Band experiment.

The FAA program plans for the L-Band ATS-6 experiment called for a set of technical and demonstration objectives as follows:

1. Acquire propagation data to investigate multipath over the ocean and over the continental United States.
2. Evaluate parametrically the performance of various avionics components including voice, data and ranging modems, and aircraft antennas.
3. Demonstrate and evaluate operational methods and concepts pertaining to the introduction of satellites in the oceanic ATC environment.

The test data, detailed analysis, and the evaluation of the results are contained in Volumes II through VII, and are described in outline form in this volume, which also contains the accomplishments and conclusions for the whole report.

The FAA ATS-6 experimental program has provided a substantial technology data base for use in the design and planning of aeronautical satellite systems for both oceanic and CONUS ATC application. Equipment designs have been tested and validated, demonstration of satellite-based air traffic control procedures for

oceanic use have been carried out, and special-purpose test equipment and techniques have been developed for use in future CONUS ATC concept experiments. Thus, the program has successfully provided a solid technical and operational foundation for future developments in satellite-aided ATC systems.

2. BACKGROUND

2.1 CURRENT OCEANIC COMMUNICATIONS

A "communication gap" exists between enroute aircraft in oceanic airspace and continental ATC facilities. Aircraft flying near the coast make use of line-of-sight very high frequency (VHF) communications, and extended range VHF communications working out to less than 400 miles. Flights in nearly all oceanic areas rely on HF frequencies with less reliable communications which are not direct pilot-to-controller but are relayed through intermediate stations from pilot-to-communications specialists-to-controller, creating unwanted delays. The aeronautical communication system in use over the Atlantic is depicted in Figure 2-1, which also indicates the organized flight tracks dictated by the present system. The majority of air-ground communications in the over-ocean message traffic are position reports from the airplane to the ground. These reports are required because there is presently no surveillance system available over the ocean. The oceanic ATC system makes use of widely spaced planned tracks across the ocean, large separation times between aircraft as they enter the track, and periodic reports by the on-board air crew as they pass certain check points along the track. Navigation and periodic reporting of position to ATC is dependent strictly on the performance of the on-board crew and equipment. In this situation, there is no mechanism whereby gross navigation error, human oversight, or gradual equipment signal drift can be detected. This can lead to the situation where the aircraft believes itself to be on course and reports accordingly, but is gradually encroaching on another track. As air traffic increases, it will be necessary to provide additional ATC system capacity by a reduction of separation standards to avoid flight delays and avoid fuel-wasteful/ uneconomical routes. An accurate satellite surveillance system would insure the present level of safety, permit fuel efficient use of the oceanic airspace for the airlines, and make possible a reduction of oceanic ATC Centers.

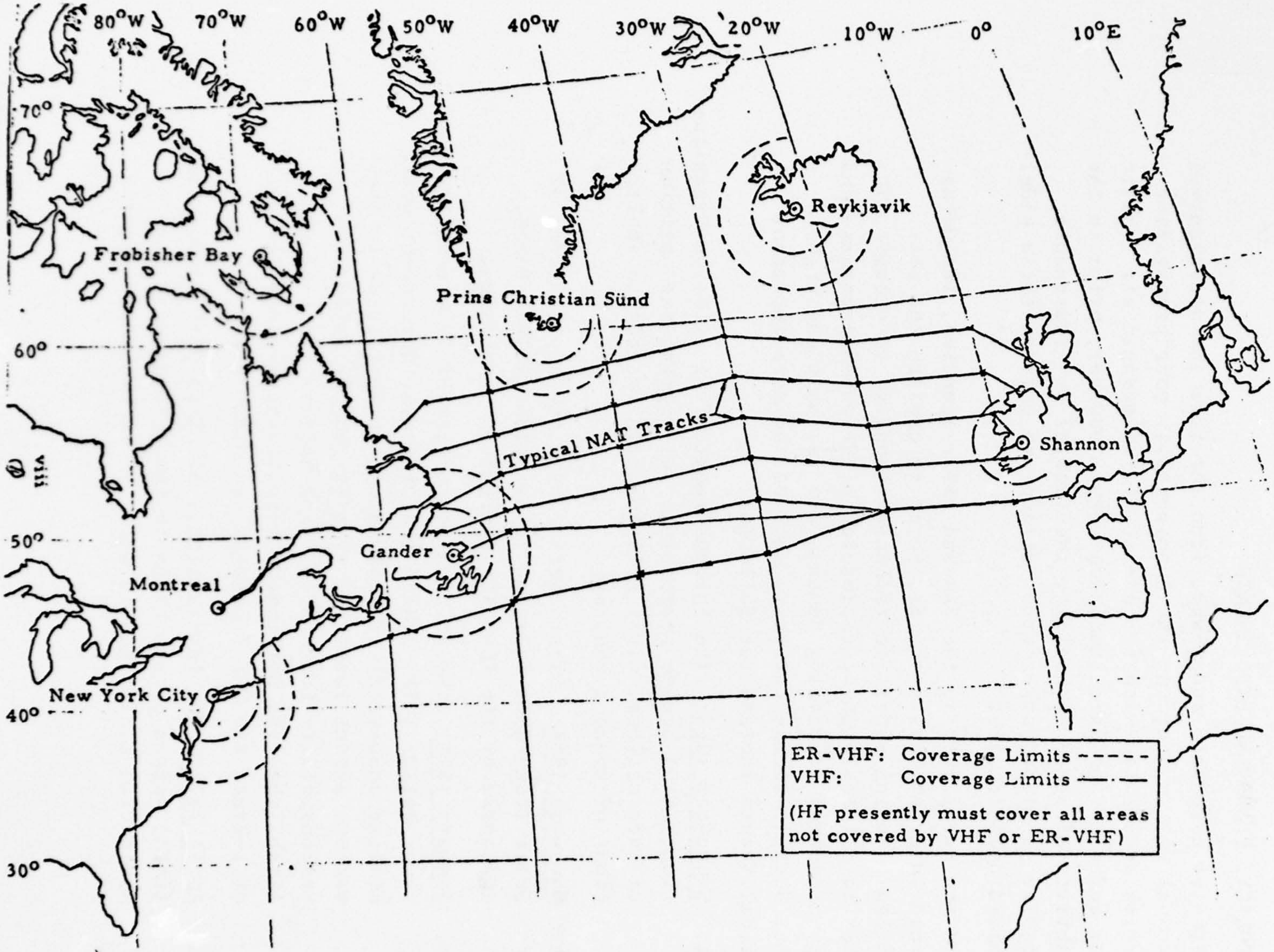


Figure 2-1. Present NAT Communications

2.2 POLICY, PLANS AND EXPERIMENTS

Studies have been under way, from the time the decision was made to use HF, to overcome the fundamentally poor propagation properties associated with the use of HF for oceanic air traffic control and other oceanic communications. However, prior to the availability of space technology, the lack of any reasonable alternative precluded any serious attempt to correct those widely recognized deficiencies.

In the early 1960's, the FAA and other agencies, including concerned international agencies, began to explore the possibilities of using satellite technology applied to oceanic ATC, in order to eliminate the deficiencies of HF communications, and satisfy projected increasing demands for reliable and higher capacity oceanic communications. Some of the more important historical events include the following:

a. September 1968: The International Civil Aviation Organization (ICAO) became responsible for stating the position of International Civil Aviation with respect to applications of space technology.

b. November 1968: First meeting of a new Applications of Space Techniques Relating to Aviation (ASTRA) Panel, sponsored by the ICAO Air Navigation Commission.

c. January 1971: The White House Office of Telecommunications Policy (OTP) stated that the U.S. Government would utilize commercial telecommunication facilities to the maximum extent feasible, transferred the basic U.S. responsibility for AEROSAT from NASA to the FAA, and established the Government's policy to promote the use of L-Band, the UHF frequency near 1600 MHz.

d. April 1972: The International Air Transport Association (IATA) made a presentation to the ICAO Seventh Air Navigation Conference in which it recommended that the

objectives of any developmental program should include among others:

1. "Evaluation of the propagation characteristics of the chosen frequency band(s).

2. Evaluation of alternative modulation techniques and of technical and operational performance of voice and data communications.

3. Assessment of the performance and characteristics of aircraft installation.

4. Determination of optimum techniques of management of voice and data communication channels and of the system control.

5. Limited trials of the use of satellite channels in the chosen ATC and operational control environments to evaluate operational applications."

e. January 1973: U.S., ESA and Canada working group reached agreement on the draft of the MOU and an AEROSAT Performance Specification.

f. May 1974: The FAA Signed the AEROSAT MOU for the U.S. followed by ESA and Canada in August 1974.

Along with the above deliberations of purpose and policy, aeronautical satellite communications experiments were conducted by the U.S. DOT and the European Space Agency.

In May 1971, the U.S. DOT Transportation Systems Center (TSC) conducted L-Band balloon experiments on the West Coast of the United States. During September-October 1971, TSC joined ESA for another series of L-Band balloon experiments in Southern France. Under FAA sponsorship, the Boeing Commercial Airplane Co. also conducted a series of L-Band propagation experiments with the NASA ATS-5 satellite from August 1969 through 1972. However, the ATS-5 satellite started spinning unstably shortly after launch, which reduced the utility of the satellite for the proposed ATC and communications experiments.

Thus, with a projected AEROSAT launch for 1979-80, the ATC experimentation and evaluation with the NASA ATS-6 satellite constituted a chronological pivotal point in terms of the availability of experimental data for the AEROSAT system design and test planning as well as for the development of satellite concepts for CONUS ATC applications.

3. OBJECTIVES

The general objectives of the Air Traffic Control (ATC) experiments and evaluations with the NASA Applications Technology Satellite, ATS-6, were to acquire satellite ATC system design data and to demonstrate direct and reliable aeronautical communications over the oceanic air routes for the purpose of establishing a positive control oceanic ATC system.

The oceanic ATC communications experiments with the NASA ATS-6 satellite were conceived and designed to be a valuable precursor to the AEROSAT program, which is designed to provide demonstration test data for a satellite-based oceanic ATC system.

The above general objectives focused upon two major activities with specific tasks and objectives:

a. Aeronautical Technology Tests

b. ATC Demonstration Tests.

3.1 THE AERONAUTICAL TECHNOLOGY TESTS

The objectives of the aeronautical tests and experiments with the NASA Applications Technology Satellite, ATS-6, were to provide the communications technology base for the forthcoming AEROSAT program. The satellite communications technology base was required to establish a direct and reliable communication link via a geostationary satellite transponder between the oceanic ATC ground station(s) and the aircraft flying over oceanic airspace. The bulk of the technical effort dealt with the communication link between the satellite transponder and the aircraft. The reasons for this are that the avionics, especially antennas, are constrained in size and cost, and have to operate with communication channel geometry which varies as a function of flight route and aircraft flight dynamics. The satellite-ground station(s) link involves technology as exemplified by various commercial satellite communications systems which support communications between two fixed ground stations and which can utilize fairly large antennas.

Below are listed some specific objectives of the aeronautical technology tests.

3.1.1 Propagation Tests

a. Oceanic Multipath -

The ATS-6 aeronautical tests were designed to provide narrow band* characterization of the oceanic communication channel, and to obtain comprehensive data regarding the effects of multipath on the aircraft-satellite link. (The multipath noise interference effects are those unwanted signals which originate at the source and impinge on the receiver after they are reflected and distorted by the earth's surfaces within the channel geometry.) Test probes of the oceanic multipath medium were conducted on eighteen occasions, covering a range of aircraft-spacecraft elevation angles from 3° to 32° and a variety of North Atlantic sea conditions. One of the objectives of the multipath tests was to compare the results with predictions based on a Gaussian scatter model as applied to a very rough surface. In addition, the data was used to validate an electronic analog instrument capable of simulating the narrowband oceanic channel.

b. CONUS Multipath -

The objective of the CONUS multipath tests with the NASA ATS-6 aeronautical communications experiment was to provide wideband* channel characterization, and obtain multipath data over the continental U.S. in support of advanced CONUS ATC system concepts of the post-1990 period, which involve satellite techniques of communication and surveillance.

CONUS multipath data complete the characterization of the satellite-aircraft channel, which is needed to support system specifications, especially aircraft position location, contained in the concepts developed for future satellite based Advanced Air Traffic Management Systems (AATMS), Report No. DOT-TSC-OST-75-32.

*Typically 100 KHz for narrowband and 10 MHz for wideband.

3.1.2 Avionics Tests

a. Modulation and Demodulation

A major objective and corresponding effort of the ATS-6 aeronautical communication tests was to evaluate various modulation and demodulation techniques for the transmission of voice, digital data and ranging signals to and from aircraft via the satellite. This objective included equipment performance evaluation of several candidate approaches to voice, digital data and ranging modems.

b. Aircraft Antenna

In a satellite based ATC system, the design of the avionics segment offers the most challenge and promises the largest payoff of all the segments of the system, when the variety and size of the aircraft population is considered. The aircraft antenna is a major component of the avionics design. Since the satellite-aircraft channel has a limited power budget, the antenna must provide sufficient gain over the required coverage area regardless of aircraft attitude and motion and, at the same time, be relatively small and easy to install or retrofit. In view of the above, the aircraft antenna test objectives included the exploration and testing of advanced high gain (10 dB) antenna designs, as well as available lower gain designs. The technical objectives of the antenna tests were to determine gain and multipath interference over a range of satellite elevation and relative bearing angles.

3.2 ATC DEMONSTRATION TESTS

The objective of this effort was to demonstrate and evaluate basic capabilities and operational concepts of a satellite communications system in the oceanic ATC environment. Specifically, the ATC demonstration objectives were:

a. To demonstrate satellite supported direct communications of voice, data, ranging and position location between test aircraft and an experimental oceanic ATC ground terminal.

b. To expose operating oceanic ATC controllers to voice communications with aircraft via the ATS-6 satellite.

c. To demonstrate the aircraft position location function of the NASA PLACE equipment.

d. To explore equipment configurations, interfaces and displays of aircraft position tracking on the oceanic ATC console.

4. TEST DESCRIPTION AND RESULTS

The operations plan for the ATS-6 integrated L-Band experiment was written by NASA Goddard Space Flight Center (GSFC) on the basis of inputs submitted by each participant and contained in the separate plans of experimentation and evaluation.

NASA-GSFC was the focal point for the operation of all the ATS-6 experiments in terms of spacecraft operation and satellite terminal communications facilities, while the individual participants were entirely responsible for the conception, design, and conduct of each experiment.

4.1 PARTICIPANTS AND LOGISTICS

The participating organizations and functions listed in Table 4-1 are an indication of the international nature as well as the complex logistics of the experiment.

The pictorial representation in Figure 4-1 shows the NASA ATS-6 experimental satellite and the L-Band antenna pattern of the satellite-aircraft communication link. The spacecraft antenna is a thirty foot diameter parabola, which is steered to illuminate any desired area within view of the satellite. The smaller satellite to the far left is the ATS-5, which was used together with the ATS-6 to demonstrate the surveillance function of the NASA/PLACE equipment.

The FAA experiments required also the use of U.S. Air Force Bases in Lajes, Azores and Loring, Maine. During the demonstration experiments, various aviation community offices were linked to FAA/NAFEC for the voice communications tests through ATS-6 satellite. One of those links involved the FAA KC135 test aircraft, 2000 miles east of NYC, and the New York ARTCC. To support multipath measurements made by aircraft over the ocean, DOT/TSC made use of a sea state measuring buoy, developed by the U.S. Navy Underwater Sound Laboratory in New London, Connecticut and operated by TSC personnel aboard the U.S.C.G. Cutter Galatin.

TABLE 4-1. PARTICIPANTS AND FACILITIES IN ATS-6 L-BAND EXPERIMENTS

Agency	Mobile Description
FAA/TSC	1-KC135 airplane
ESA (aircraft)	1-Comet airplane
Canada, Ministry of Transport	1-Lockheed Jetstar
DOC/MARAD	2-cargo ships - American Alliance and Lash Atlantico
USCG/TSC	2-Cutters, Galatin and Sherman
ESA(Maritime)	German ship, Otto Hahn
Federal Republic of Germany	Emergency Position Indicating Radio Beacon **(EPIRB)** Buoy

Agency	Ground Station
FAA/NAFEC	**Experimental Oceanic ATC Ground Terminal**
NASA/Goddard Space Flight Center	Applications Technology Satellite Operations Control Center
NASA/Roseman NC	ATS-6 Ground Station Earth Terminal
NASA/MOJAVE	**Alternative ATS-6** Ground Station
Canada, Ministry of Transport	Ottawa Ground Terminal
Transportation Systems Center	ATS-6 Technology Experiment Coordination Center and Westford Ground Station
DOC/MARAD	Kings Point Maritime Ground Station
USCG/New York City	Rescue Coordination and AMVER

Figure 4-1. ATS-6 AERO/MAR Experiment Pictorial Configuration

The link configuration of the DOT/FAA experiments is portrayed in Figure 4-2, and the demonstration system configuration of the ATC experimentation and evaluation tests is given in Figure 4-3.

FAA/NAFEC and the DOT/Transportation Systems Center enlisted the support of various organizations from the private sector for analytical support, for the preparation of special communications equipment and for the execution of the ATC experiments. A partial list includes:

Boeing	Washington
CNR Inc.	Massachusetts
Stein Associates	Massachusetts
Magnavox Research Lab	California
Bell Aerospace	New York
Ball Brothers	Colorado

Boeing Commercial Airplane Co. was the primary system test contractor to TSC for the ATC Technology experiments, with personnel assigned to the FAA test aircraft and NASA/ROSMAN satellite ground station. Personnel from FAA-NAFEC performed the ATC demonstration tests and manned the test aircraft, as well as the NAFEC Ground Terminal.

4.2 THE TEST PLANS

The U.S. aeronautical ATS-6 L-Band experiment test plan was developed under the direction of the DOT/FAA and consisted of two parts:

a. Aeronautical technology test plan prepared by the Transportation Systems Center

b. ATC demonstrations test plan prepared by FAA/NAFEC.

The test plans described in detail all components of each experiment as follows:

1. Type of experiment
2. Objectives and rationale

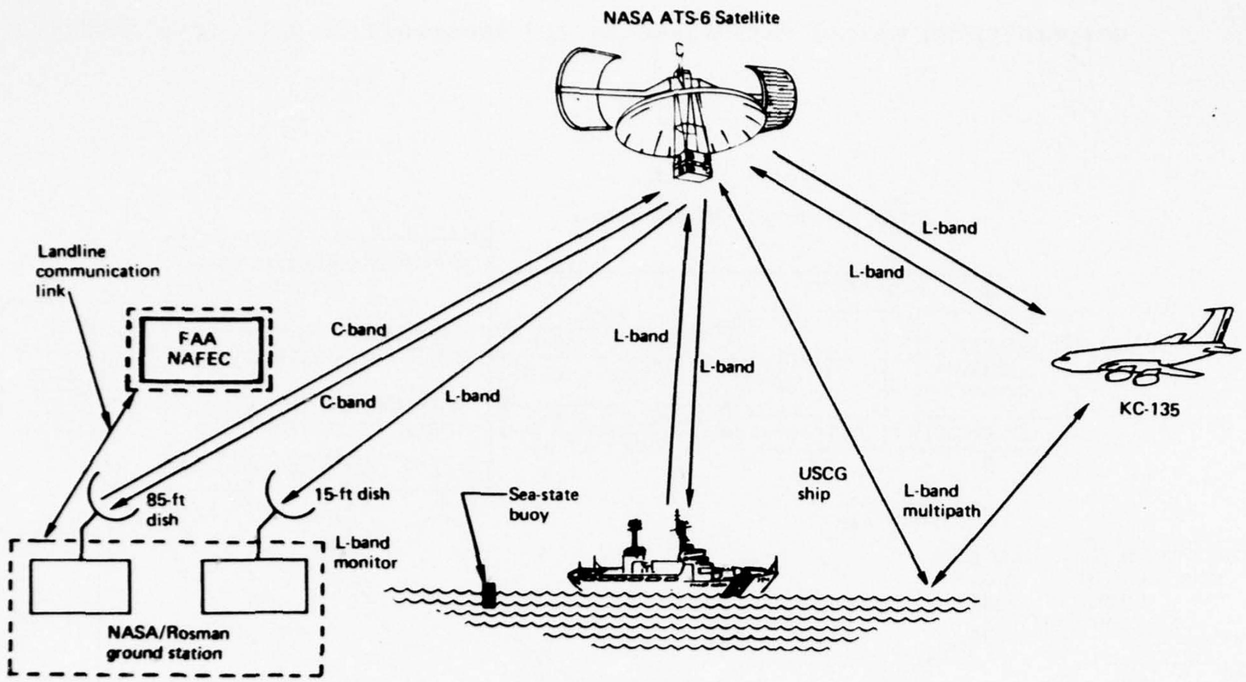


Figure 4-2. Link Configuration for DOT/FAA ATS-6 L-Band ATC Experiments

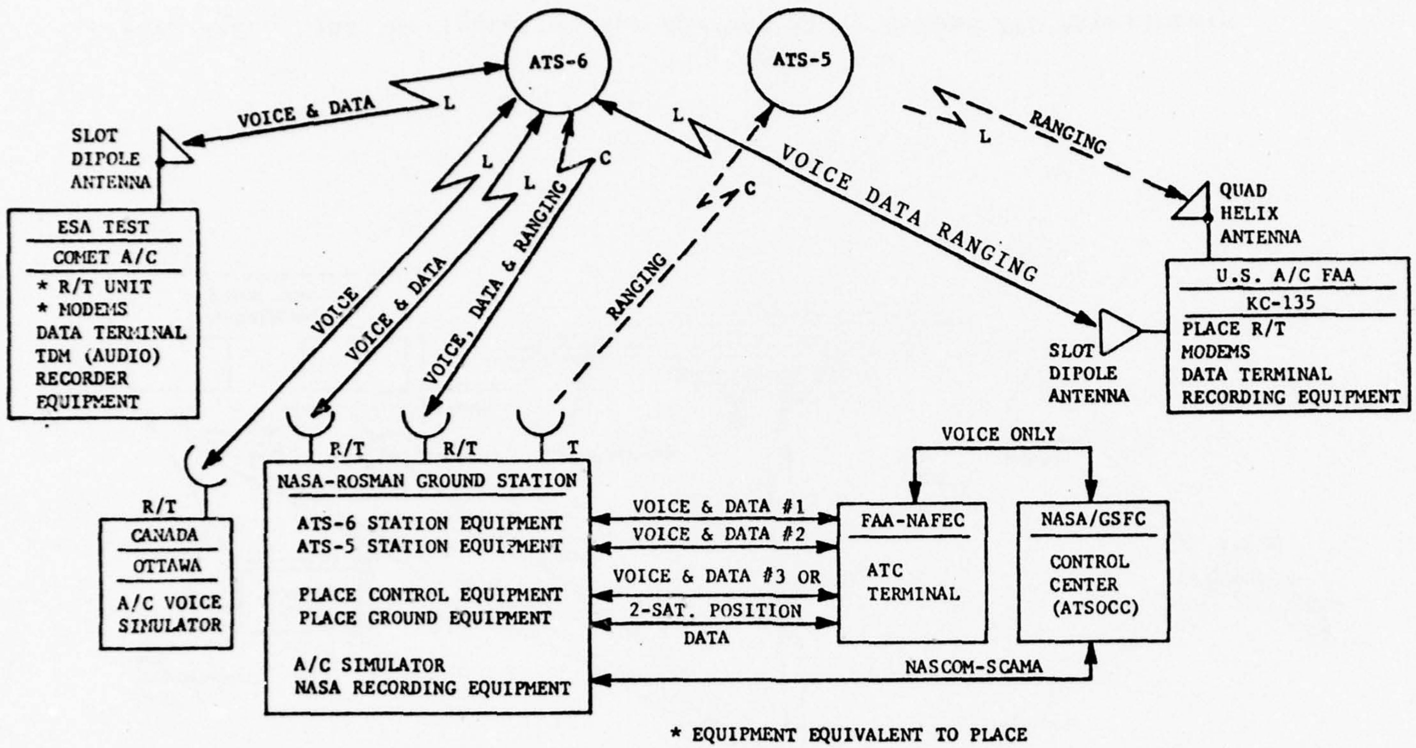


Figure 4-3. ATS-6 Experiment ATC Demonstration System Configuration

3. Frequency plans, power levels, and ATS-6 antenna requirement

4. Aircraft base of operations and flight schedule

5. Ground stations and personnel participation

The test plans contained specific data reduction and analysis procedures for the evaluation of the test results. Quick-look procedures were instituted to interact with the experiment in progress, in order to safeguard against costly testing without obtaining useful data.

The DOT/FAA test plans were designed to insure that each experiment would have sufficient testing time, so that the data and the results would permit full characterization of all parameters of interest. Care was exercised to correlate the data of each experiment with the performance of the communication channel. This concern is especially applicable to the interaction of multipath interference with the voice and data modems which were extensively tested under the technology program. For this reason, two types of tests were performed. Type I tests determined system performance with signals as received by the avionics and antennas under test. Type II tests evaluated system performance by controlling the level of multipath interference mixed with the direct satellite signal. The interference signal was obtained from a separate aircraft antenna looking down toward the ocean and receiving only the multipath signal.

Voice modem evaluations were accomplished by performing intelligibility scoring of the voice recordings made over the aircraft-satellite channel. CBS Technology Center performed the voice intelligibility scoring under contract to DOT/TSC.

4.3 TEST DATA AND RESULTS

All objectives of the ATS-6 Aeronautical Satellite tests were accomplished. In terms of test data time as shown in Table 4-2, over 300 hours of actual test time were logged with the ATS-6 satellite vs. 276 hours budgeted with NASA during the planning

TABLE 4-2. ATS-6 AERONAUTICAL SATELLITE TEST TIME

TEST NAME	PLANNED DATA (HRS)	ACQUIRED DATA (HRS)
Checkout	4	36
TECHNOLOGY TESTS		
MULTIPATH		
- Oceanic	19	18
- CONUS	20	25
MODEMS		
- Voice	35.3	31.3
- Data	32.6	27.3
- Voice and Data	6.9	6
- Ranging	13.8	11.3
ANTENNAS	3.5	9
ATC DEMONSTRATION		
- Voice Only	36	36
- Data Only	36	36
- Voice and Data	36	36
- 2 Satellite Position Det.	9	25
- Joint Demonstration (FAA, ESA, and (CANADA)	24	16
TOTALS	276.1	312.9

phases. In many cases, several tests were conducted simultaneously, e.g., all digital data modems (5) were tested simultaneously over the link under the same parametric conditions. This enabled a direct and valid comparison of the performance of competing techniques for the AEROSAT system. Accounting for simultaneous testing, well over 1000 hours of satellite communications technology data was acquired in the DOT/FAA ATS-6 experiments.

The important conclusions of the ATS-6 Aeronautical Satellite tests are highlighted below. A detailed technical summary of all data, analysis and conclusions appears in Volume III of this report. Volume II covers the ATC demonstration tests and Volumes IV through VII contain the details of the aeronautical technology tests.

4.3.1 The Aeronautical Technology Tests

The data and results of the ATS-6 aeronautical technology tests provide the technology base enabling equipment specification, design of system configurations, and valid performance predictions. Furthermore, the ATC operational evaluations with ATS-6 satellite provide the insight for preparation of test plans for conducting operational tests with AEROSAT. The ATS-6 test results are a first step in acquiring a technology data base helpful to further CONUS ATC satellite concept development and guidelines for future test planning. Some sample data and specific results of the FAA technology tests are given below.

a. Oceanic Multipath -

A summary of measured oceanic multipath parameters is presented in Table 4-3. The results of the multipath measurements and analysis experimentally verified the Gaussian scatter model of the satellite to aircraft channel. This enables the complete characterization of the narrowband oceanic aircraft-satellite channel statistics by means of the delay-Doppler scatter function, which represents the power spectral density of the multipath signal,

TABLE 4-3. SUMMARY OF SELECTED MEASURED OCEANIC MULTIPATH PARAMETERS

			Typical Value at Grazing Angle Specified		
Parameter	Notes	Measured Range	8°	15°	30°
RMS scatter coefficient (horizontal polarization)	b	-5.5 to 0.5 dB	-2.5 dB	-1.0 dB	-1.0 dB
RMS scatter coefficient (vertical polarization)	a	-15.0 to -2.5 dB	-14.0 dB	-9.0 dB	-3.5 dB
Delay spread	b				
3-dB value		0.25 to 1.8 μsec	0.6 μsec	0.8 μsec	0.8 μsec
10-dB value		2.2 to 5.6 μsec	2.8 μsec	3.2 μsec	3.2 μsec
Coherence bandwidth (3-dB value)	b	70 to 380 kHz	160 KHz	200 KHz	200 KHz
Doppler spread (in-plane geometry)	c				
3-dB value		4 to 190 Hz	5 Hz	70 Hz	140 Hz
10-dB value		13 to 350 Hz	44 Hz	180 Hz	350 Hz
Doppler spread (cross plane geometry)	c				
3-dB value		79 to 240 Hz	79Hz*	110 Hz	190 Hz
10-dB value		180 to 560 Hz	180 Hz*	280 Hz*	470 Hz
Decorrelation time (3-dB value)	d	1.3 to 10 msec	7.5 msec	3.2 msec	2.2 msec

[a] Strong dependence on grazing angle, especially near Brewster angle
[b] No strong grazing-angle dependence
[c] Strong grazing-angle dependence
[d] Strong inverse dependence on grazing angle
* At 10° grazing angle

arriving at the aircraft receiver with delay and Doppler shift . Multipath test data further validated the electronic analog multipath channel simulator facility at the Transportation Systems Center in Cambridge. This electrical analog channel simulation instrument can, therefore, be used reliably for laboratory testing of multipath effects on modems prior to field testing. This process eliminates the less desirable candidate modems and avoids a number of costly flight tests.

The multipath test results obtained with ATS-6 satellite experimentation will be used in the design of the signal structure and the avionics hardware for AEROSAT applications.

b. **CONUS Multipath-**

A summary of typical values and the measured spread of selected CONUS multipath channel parameters is given in Table 4-4. Several delay-Doppler scatter function time histories were obtained as the aircraft traversed variable terrain conditions. These data indicate a high degree of multipath reflected signal strength variation. In general, the level of the multipath return was far below that of oceanic reflections (< 10dB). Over large lake regions, multipath signal levels were comparable to those experienced over the ocean. It may be concluded that over water reflections are a worst case multipath assumption for the CONUS satellite aircraft channel. CONUS multipath data obtained during aircraft approach and landing indicated large signal to interference (S/I) degradation attributed to steep aircraft banking maneuvers. Under these conditions the lower hemispherical multipath rejection properties of the antenna were negated. Also, during aircraft taxi maneuvers on the ground, significant amplitude fluctuation was observed, which is attributed to building shielding and aircraft orientation. Owing to the preponderance of multipath level variations, it was not possible to obtain adequate statistical averages of the multipath parameters. Satellite communications system concepts for the CONUS ATC will, therefore, require additional multipath data in order to characterize the overland multipath channel.

TABLE 4-4. SUMMARY OF MEASURED CONUS MULTIPATH PARAMETERS

Parameter	Measured Spread	Typical Value
RMS scatter coefficient (horizontal polarization):	-18 to +2 dB	-9 dB
RMS scatter coefficent (vertical polarization):	-21 to -3 dB	-13 dB
Delay spread (3-dB):	0.1 to 1.2 μsec	0.3 μsec
Delay spread (10-dB):	0.2 to 3.0 μsec	1.2 μsec
Coherence bandwidth (3-dB):	150 KHz to 3.0 MHZ	600 KHz
Doppler spread (3-dB):	20 to 140 Hz	60 Hz
Doppler spread (10-dB)	40 to 500 Hz	200 Hz
Decorrelation time (3-dB):	1 to 10 msec	4 msec

c. Modulation/Demodulation-

Techniques of modulation/demodulation, exemplified by a number of voice, digital data and ranging modems, were tested during the ATS-6 L-Band experiment. The data and the test results are summarized separately for each modem category.

1. Voice Modems

A summary of voice modem performance is contained in the intelligibility curves of Figure 4-4. The curves shown are actually best fits to experimental data obtained over several months of various test conditions. The results show that all modems except one* achieved an intelligibility score in excess of 70 percent, using a phonetically balanced (PB) word list, at a channel quality of 43 dBHz, which is the minimum level specified for the AEROSAT communications link. The Hybrid I voice modem achieved a score in excess of 70 percent word intelligibility at 40 dBHz. The 70 percent score is equivalent to receiving, correctly, 95 percent ATC sentence messages.

The Adaptive Delta Voice Modulation (ADVM) modem was tested using two detection options, one digital and the other analog. Test results indicate that the analog is superior to the digital detection scheme. The ADVM modem, in the analog mode, ranked second among the voice modems tested.

The most significant results of the voice modulation experiment are obtained with type II tests which showed that voice intelligibility degradation is not detectable with S/I ratios as low as 3 dB.

2. Digital Data Modems

Digital data modem results are found in a series of curves contained in Volume VI of this report under Modem Evaluation

*The specific older design adaptive narrowband frequency modulation (ANBFM) modem showed inferior performance.

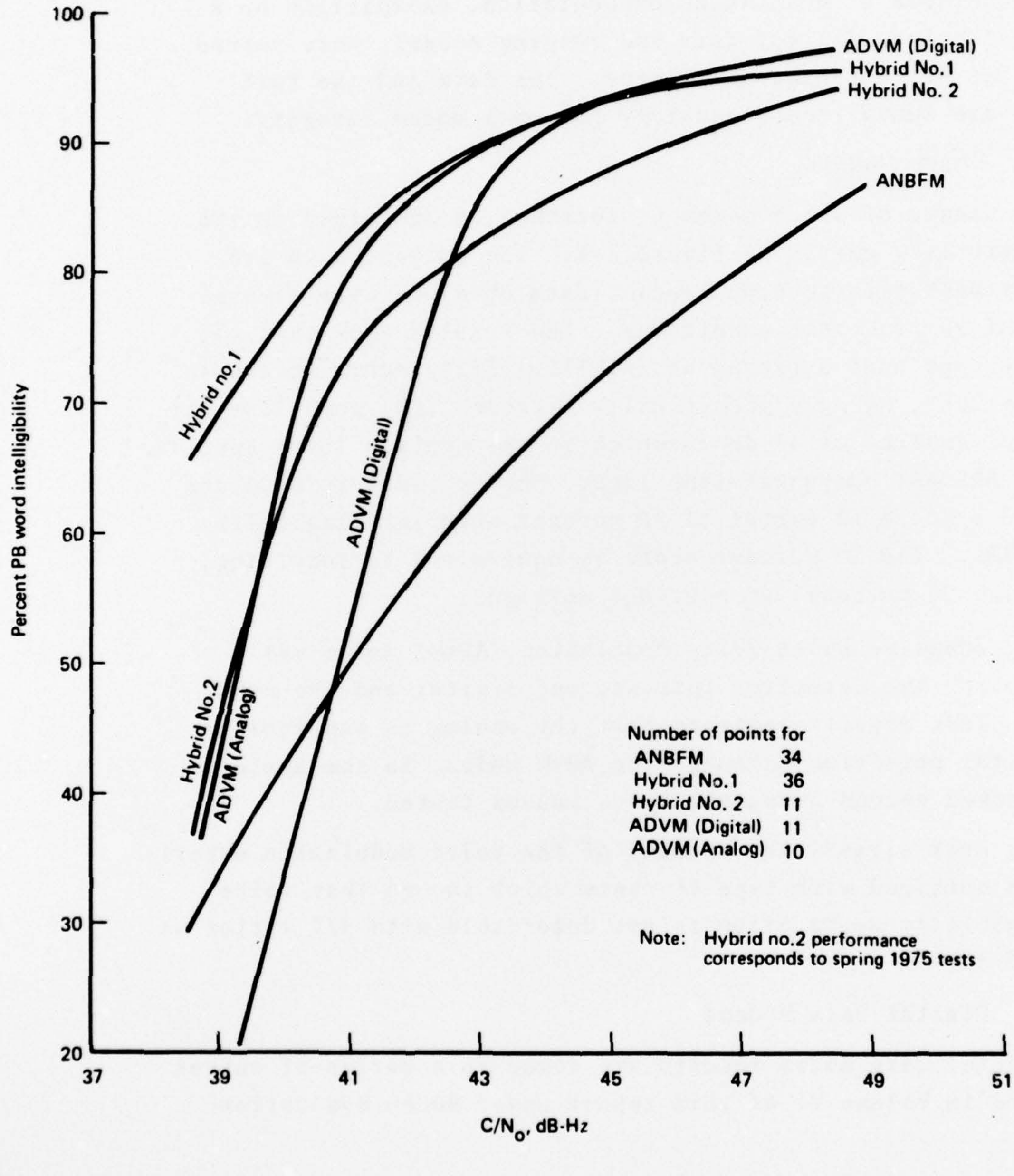


Figure 4-4. Summary Comparison of Voice Modem Performance, Type I Tests

Test, Volume VI. A sample curve is shown in Figure 4-5 which clearly shows the degradation of modem performance with decreasing signal to interference values obtained during type II tests.

Five digital data modems, each operating at 1200 bits per second (BPS), were evaluated simultaneously in terms of average bit-error-rate (BER) and burst error behavior. During the type I tests using a three-element slot-dipole antenna system, which has relatively high multipath rejection, all modems met the AEROSAT system specification of 10^{-5} error probability at C/N_o = 43 dBHz. With this antenna system, the results showed that the effects of multipath were not pronounced for the test conditions experienced. However, during type II tests, as the multipath levels increased, the BER performance of all data modems degrades severely, and in terms of burst error behavior, error bunching occurred as a result of multipath fading. In this case, in order to maintain a specified 10^{-5} error probability at the 43 dBHz power level, error correction coding or multipath tolerant modem design appears to be a requirement.

3. Ranging Modems

Range measurements between ground station and aircraft, via satellite transponder, constitute the technology baseline for the implementation of a satellite survellance system for oceanic ATC. The ranging modem tests were designed to provide position determination performance in terms of one way relative range error.

Two different ranging modems were designed and tested, the TSC digital tone modem operating on clock frequencies of 19.53 kHz narrowband, 156.25 kHz wideband, the NASA/PLACE modem operating on a clock frequency of 8.6 kHz, narrowband only. Notwithstanding certain equipment difficulties, the test results indicate that in the narrowband mode, at C/No = 43 dBHz, typical RMS one way range errors, 1σ, were: TSC modem 100 meters; NASA modem 276 meters. In the wideband mode, the RMS error was roughly 30 meters for the TSC modem. The current AEROSAT system design goal calls

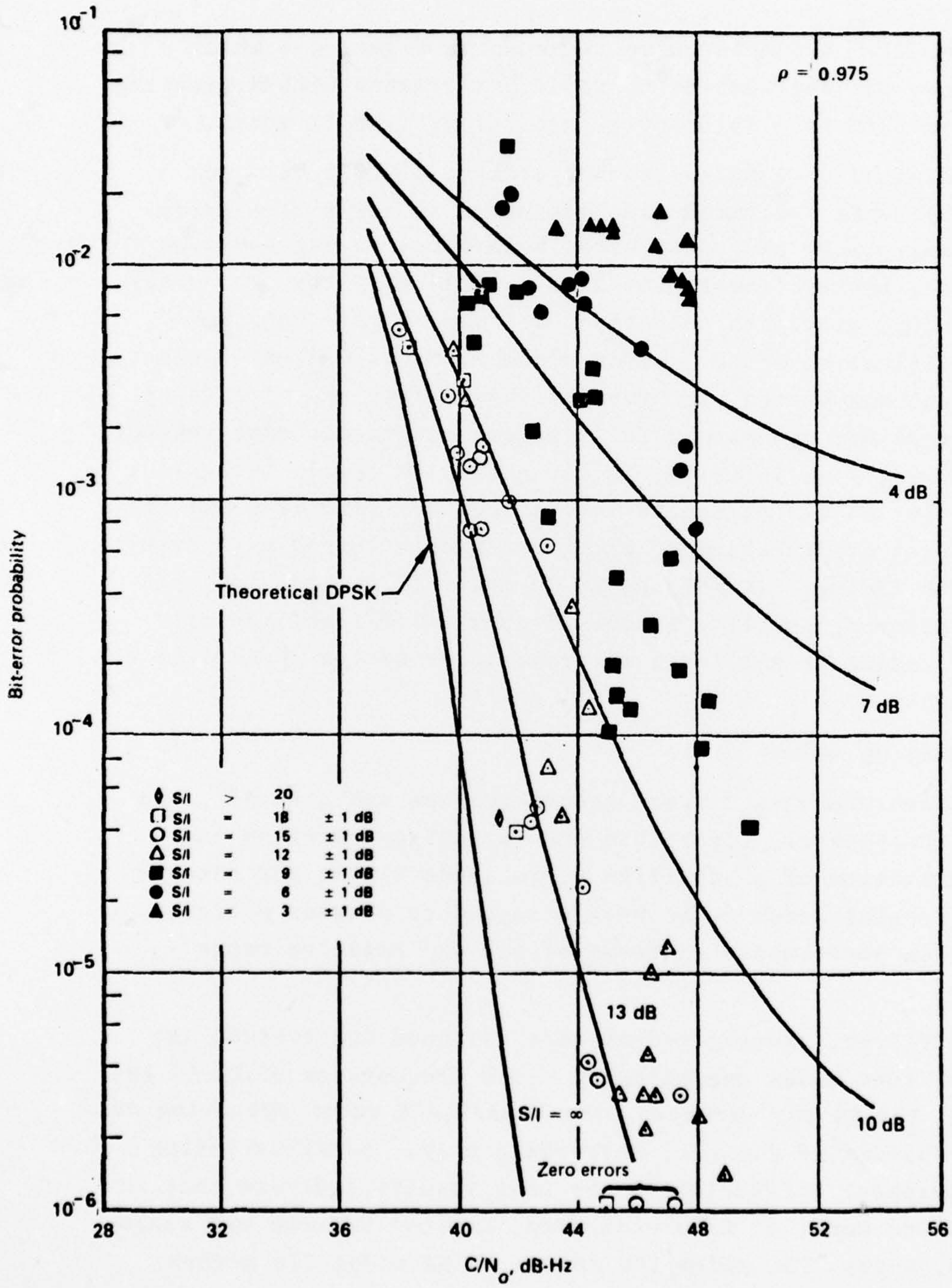


Figure 4-5. Bit Error Rate Performance of FAA DPSK Demodulator, 1200 bits/s, Type II Tests

for one way ranging RMS error, 1σ, of 50 meters at C/N_0 = 43 dBHz. Thus, the AEROSAT ranging modem would have to be designed with some care and perhaps use multipath tolerant design techniques.

d. Aircraft Antennas-

Several different aircraft antenna types were evaluated during the ATS-6 test program. The principal antennas were:

1. Slot-dipole antenna - deployed as a system giving nearly hemispherical coverage with minimum 4 dB gain. The 3-element slot-dipole system tested consisted of one element in each of the wing root fairings, and one on the top center line with switch selection of the appropriate antenna.
2. Electronically steerable microstrip phased array - this is an 8-element linear array conformally mounted on the surface of one side of the aircraft and giving coverage to that side. Peak gain for this antenna exceeds 12 dB. More than one array is necessary for full coverage. This antenna was designed for receive only operation.
3. Microstrip element ("patch") - this single microstrip element was mounted forward on the top center line surface to provide coverage in the forward direction.

The antenna parameters of interest in this application are the antenna gain and the signal-to-interference ratio (S/I) which indicates rejection of multipath interference.

As a representative sample of the results obtained, Figure 4-6 shows gain for the 3-element slot-dipole system and indicates the margin by which this system exceeds the 4 dB minimum gain specified for AEROSAT. In addition, the experimental data with this antenna showed very good multipath rejection of 15 dB or greater for geometries typical of oceanic applications.

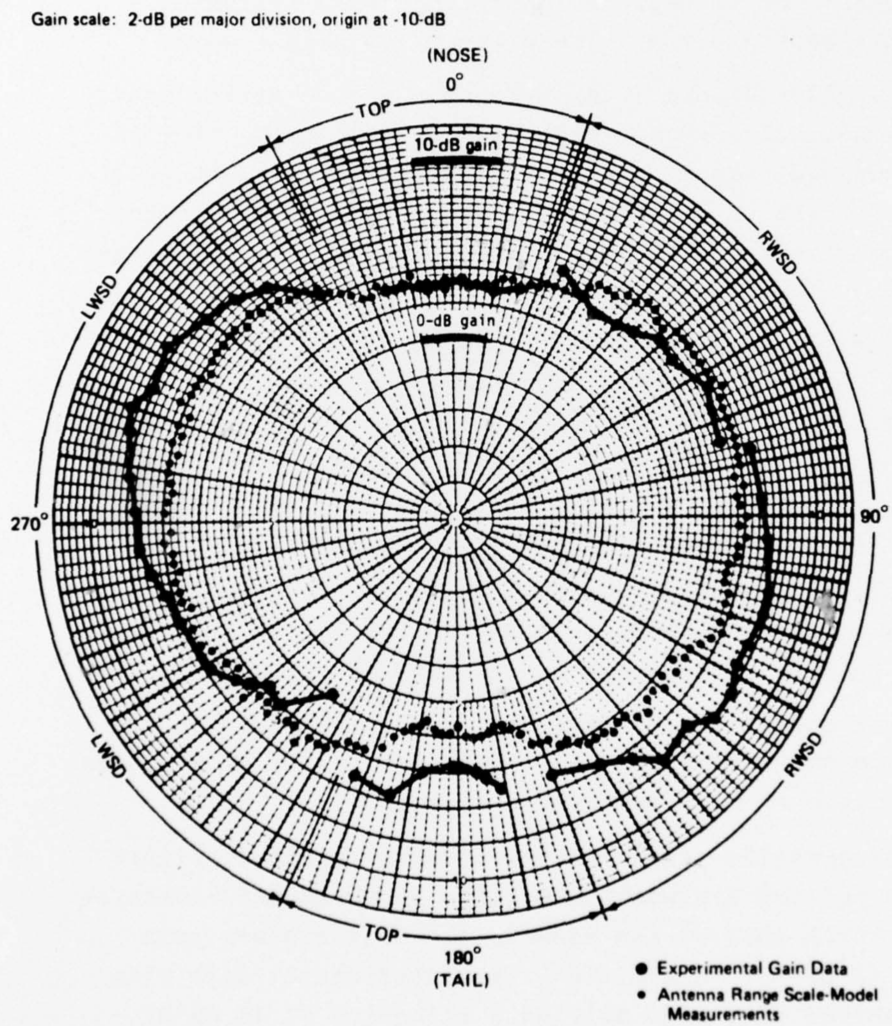


Figure 4-6. Slot-Dipole-System Composite Gain at 20° Elevation

The microstrip phased array antenna and the single element microstrip "patch" antenna were tested in the receive-only mode. The phased array is a higher cost antenna system of higher performance with integrated values of gain mostly greater than 10 dB and consistently good multipath rejection (>20dB) within the designed coverage region.

The single element microstrip "patch" was placed on the aircraft so as to provide coverage in the forward direction at medium elevation angles. The limited data collected shows the expected low gain and high multipath rejection for an element in this location. This small, rather inexpensive element features simple, conformal installation on the aircraft surface.

Of the antenna types tested, the three-element group of slot-dipoles is considered a satisfactory baseline reference antenna for AEROSAT applications. The other antennas make use of advanced microstrip elements with inherent advantages of low fabrication cost and ease of installation, even in complex array configurations. This developing technology has additional potential benefits in possible reductions in satellite and avionics costs.

4.3.2 ATC Demonstration Tests

The ATC demonstration system featured satellite supported real time voice, digital data, and ranging communications between test bed aircraft and an experimental oceanic ATC ground terminal. Satellite channel voice communication was also established between the KC-135 test aircraft and various aviation community offices through the NAFEC ground terminal telephone provisions. One such voice communication involved an operating oceanic air traffic controller at the New York Air Route Traffic Control Center (ARTCC). In his words, "that was the best communication I have had in my four years experience working oceanic air traffic control." Data communication at the KC-135 aircraft and the NAFEC

ground terminals were of good quality and reliability for both aircraft position polls and text message categories.

Using the NASA PLACE receiver equipment, three independent surveillance demonstrations were accomplished. The NASA projected position fix accuracy of 2 kilometers was not realized. Current work at NASA/GSFC has resulted in software programs which will improve considerably the satellite ephemeris data and thus reduce one error component in the aircraft position location measurements. The demonstration did successfully implement equipment configurations and interfaces for displaying on the oceanic ATC console two distinct methods of aircraft position location which are applicable to the surveillance function:

a. Aircraft position reports derived from on-board INS equipment

b. Position information derived from ground equipment using aircraft-satellite ranging data.

5. ACCOMPLISHMENTS AND CONCLUSIONS

The DOT/FAA ATC experimentation and evaluation tests with the NASA ATS-6 satellite have produced data and results which are a valuable communication technology base for the aviation community. Volumes II through VII of this report have been widely disseminated to Federal agencies and departments, avionics manufacturers, various universities and international organizations. The multipath data, in particular, has found immediate application by system development organizations responsible for the NASA Telemetry and Data Relay Satellite System and the DOD NAVSTAR Global Positioning Satellite System.

The multipath channel simulator instrument developed by DOT/FAA and validated by the ATS-6 experiment has been used by French, Canadian and U.S. organizations in modem testing for the AEROSAT system.

The accomplishments of the ATS-6 FAA experiment are:

a. Acquisition of technical data fundamental to the design of Satellite ATC systems.

b. Test and rating of L-Band components suitable for aeronautical services. The results of these tests have been utilized directly in preparing specifications for procurement of avionics test hardware for AEROSAT.

c. Validation of laboratory simulation models for synthesizing propagation phenomena. Scientists and engineers can now obtain reliable knowledge on multipath propagation using laboratory simulation without resorting to costly flight tests.

d. Demonstration of pilot/controller communications and surveillance in satellite ATC systems. These tests were forerunners of the planned AEROSAT evaluation tests. The procedures tested and the experience gained are beneficial to the preparation of international test and evaluation plans for oceanic ATC experiments with satellites.

e. Demonstration of the advantages of a coordinated USCG, ESA and FAA effort using satellites to interconnect widely dispersed aircraft and ships in a search and rescue operation. The usefulness of satellities in conjunction with emergency notification procedures was borne out in demonstrating significant reduction in the distress alerting interval.

f. Participation in an international and interagency coordinated experimental and technology sharing program. The results of these experiments are of direct interest to the following: International Civil Aviation Organization (ICAO), International Telecommunication Union, International Radio Consultative Committee (ITU/CCIR), International Union of Radio Science (URSI), and, the Advisory Group for Aerospace Research and Development (AGARD) under NATO.

In conclusion, the ATS-6 experimental program has provided a substantial technology data base for use in the design and planning of aeronautical satellite systems for both oceanic and CONUS application. Equipment designs have been tested and validated, demonstration of satellite-based air traffic control procedures for oceanic use have been carried out, and special-purpose equipment and techniques have been developed for use in future CONUS ATC concept experiments. Thus, the program has successfully provided a solid technical and operational foundation for future developments in satellite-based ATC systems.

400 Copies